# NASA DoD Consortia: -55 C to+125 C Thermal Cycle Test Results

**Dave Hillman, Ross Wilcoxon, Tim Pearson**

**Rockwell Collins**
**Cedar Rapids IA**

**SMTAI Conference Orlando 2010**

# Agenda:

- Background
- Objective
- Test Vehicle & Components
- Rework – Test Vehicle & Components
- Thermal Cycle Specifics
- Test Analysis & Results
- Future Work & Preliminary FA Results
- Questions

# Background:

## “Phase I”

**The JCAA/JGPP investigation selected the following solder alloys for testing:**

**Sn3.9Ag0.6Cu** (SAC396) for reflow and wave soldering

**Sn3.4Ag1.0Cu3.3Bi** (SACB) for reflow soldering

**Sn0.7Cu0.05Ni** (SNIC) for wave soldering

**Sn37Pb** (SnPb) for reflow and wave soldering

## “Phase II”

**The NASA DoD Lead-free investigation selected these solder alloys for testing:**

**Sn3.0Ag0.5Cu** (SAC305) for reflow and manual soldering

**Sn0.7Cu0.05Ni** (SN100C or “SNIC”) for reflow, wave, and manual soldering

**Sn37Pb** (SnPb) for reflow, wave, and manual soldering

# Background:

- **Determine the reliability of reworked solder joints in high-reliability military and aerospace electronics assemblies including mixed metallurgy situations.**
- **Assess the process parameters for reworking high-reliability lead-free military and aerospace electronics assemblies.**
- **Assess the reliability of chip scale packages (CSPs) and quad flat pack no-lead package (QFNs)**
- **Characterize the solder joint reliability of the test vehicles under Drop Shock test conditions**

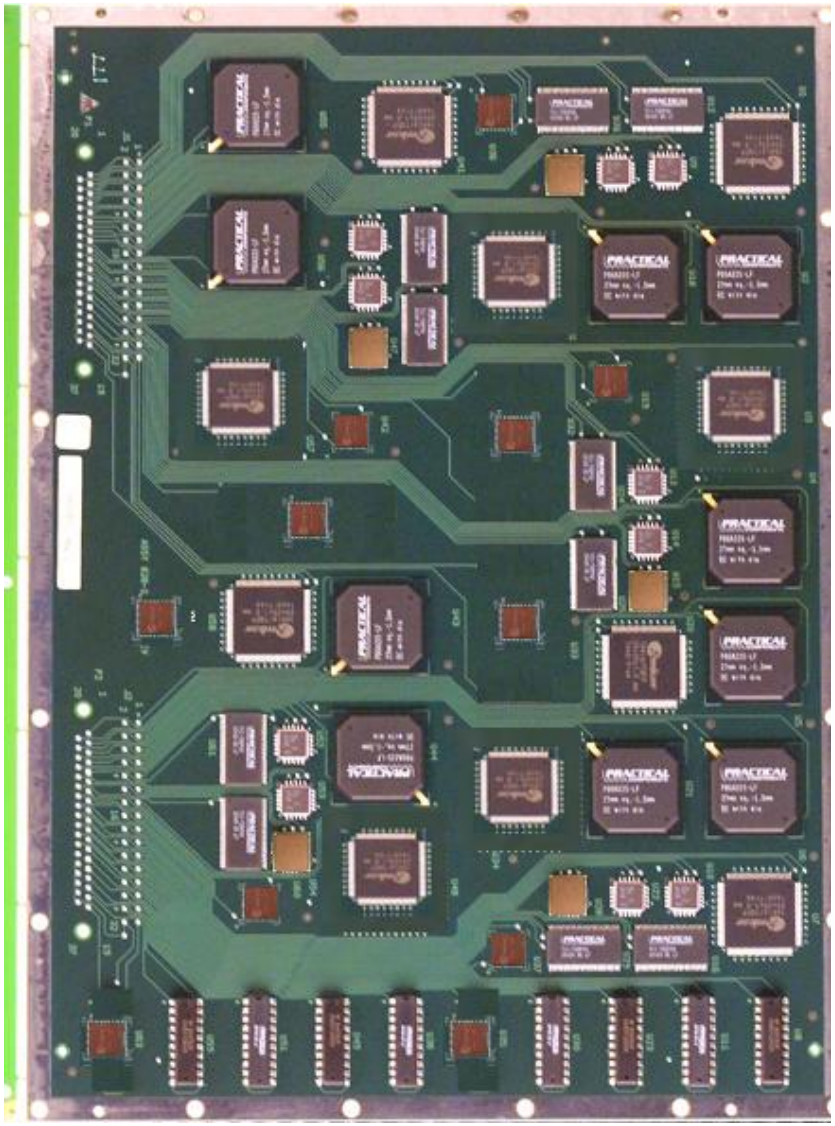
# Objective:

**The objective of the investigation was to compare the solder joint integrity of selected lead-free solder alloys to Sn63/Pb37 solder alloy for a -55 C to +125 C temperature range in accordance with the IPC-9701 specification under various as-manufactured and reworked conditions.**

**The objective of this presentation is to show results to date for testing through 3600 thermal cycles.**

# Test Vehicle & Components

- 14.5” W x 9” inches H x 0.090” T
  - 36.8 cm x 22.9 cm x 2.29 mm
- 6 layers of 0.5 ounce copper.
- IPC-6012, Class 3, Type 3 requirements.
- FR4 per IPC-4101/26 with a minimum Tg of 170ºC
- Immersion silver surface finish with a small subset of electroless nickel / immersion gold (ENIG)
- 193 test vehicles total
- Same test vehicle fabricator as Phase I



# Test Vehicle & Components

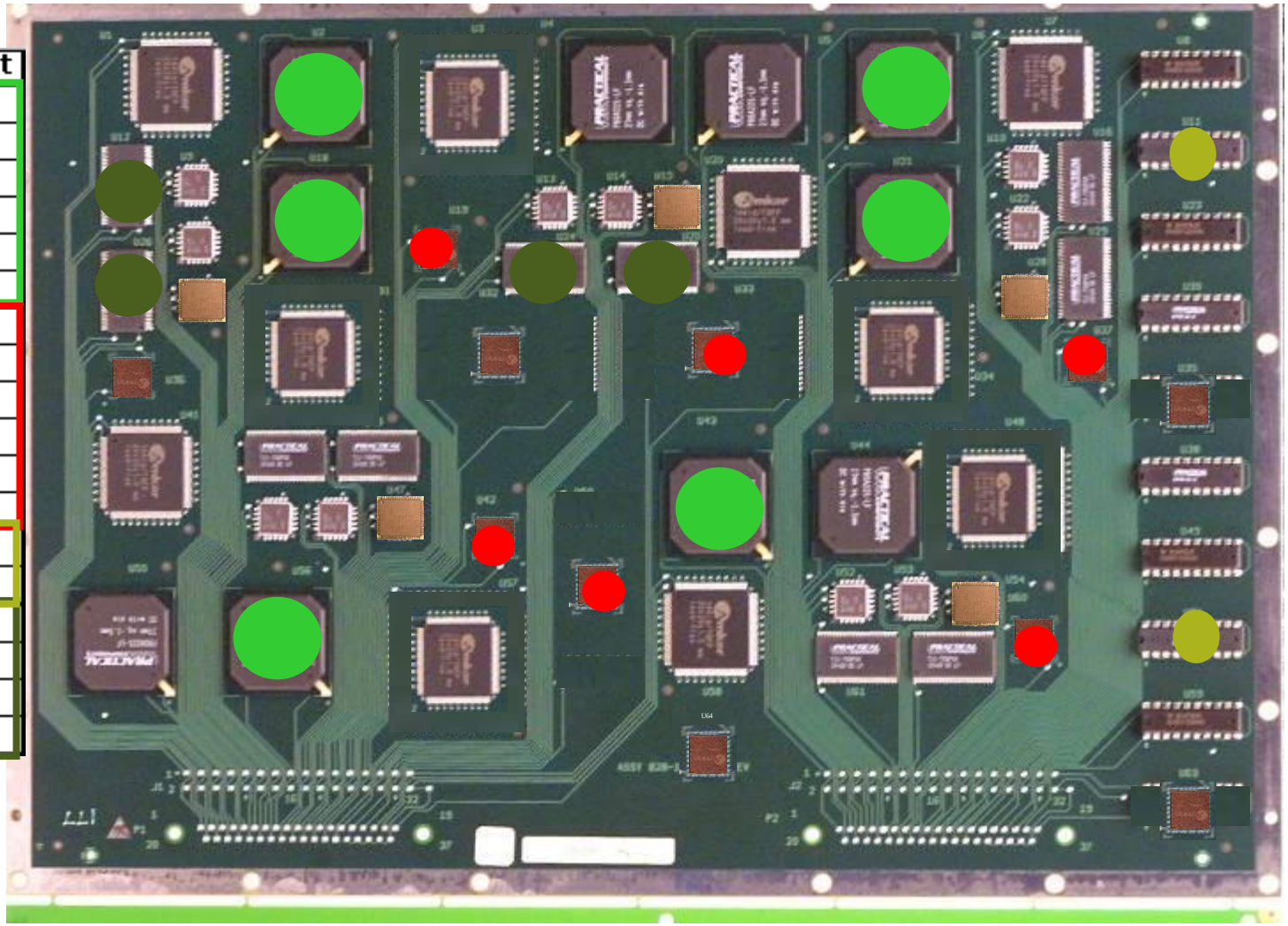
| Component Type | Component Finish | Part Number |
|---|---|---|
| CLCC-20 | SAC305 | 20LCC-1.27mm-8.9mm-DC |
| | SnPb | |
| QFN-20 | Sn | A-MLF20-.5mm-.65mm-DC |
| | SnPb | |
| QFP-144 | Sn | A-TQFP144-20mm-.5mm-2.0-DC |
| | SnPb | |
| | NiPdAu | |
| | SAC305 | |
| PBGA-225 | SnPb | PBGA225-1.5mm-27mm-DC |
| | SAC405 | |
| PDIP-20 | Sn | A-PDIP20T-7.6mm-DC |
| | NiPdAu | |
| | SnPb | |
| CSP-100 | SnPb | A-CABGA100-.8mm-1.0mm-DC |
| | SAC105 | |
| | SN100C | |
| TSOP-50 | Sn | A-TII-TSOP50-10.16x20.95mm-.8mm-DC |
| | SnBi | |
| | SnPb | |

# Test Vehicle & Components

- All test vehicles were categorized as “Manufactured” or “Reworked”.
  - “Manufactured” test vehicles represent printed wiring assemblies newly manufactured for use in new product.
  - “Rework” test vehicles represent printed wiring assemblies manufactured and reworked prior to being tested.
- Mixed metallurgy situations:
  - Forward Compatibility: a SnPb component is attached to a printed wiring assembly using lead-free solder with a lead-free profile.
  - Backward compatibility: a lead-free is component attached to a printed wiring assembly using SnPb solder with a SnPb solder profile.

# Rework Phase: Test Vehicle & Components

| RefDes | Component |
|---|---|
| U18 | BGA-225 |
| U43 | BGA-225 |
| U06 | BGA-225 |
| U02 | BGA-225 |
| U21 | BGA-225 |
| U56 | BGA-225 |
| U33 | CSP-100 |
| U50 | CSP-100 |
| U19 | CSP-100 |
| U37 | CSP-100 |
| U42 | CSP-100 |
| U60 | CSP-100 |
| U11 | PDIP-20 |
| U51 | PDIP-20 |
| U12 | TSOP-50 |
| U25 | TSOP-50 |
| U24 | TSOP-50 |
| U26 | TSOP-50 |



- Rework protocol was based on IPC rework/repair specifications with tailoring
- Rework Facilities: Rockwell Collins, Lockheed Martin, BAE Systems

# 'Bonus' Test Vehicle & Components

**•Naval Surface Warfare Center Crane Division**
**(a NASA-DoD Consortium member)**

- **Funded/Supplied 30 test vehicles to the NASA-DoD project in support of their Naval Supply Command (NAVSUP) sponsored "Logistics Impact of Lead-Free Circuits/Components" project**

- **The primary purpose of the 30 test vehicles: Perform multiple pass SnPb rework, once or twice, or randomly selected lead-free DIP, TQFP-144, TSOP-50, CLCC and QFN components from SAC305 and SN100C soldered assemblies.**

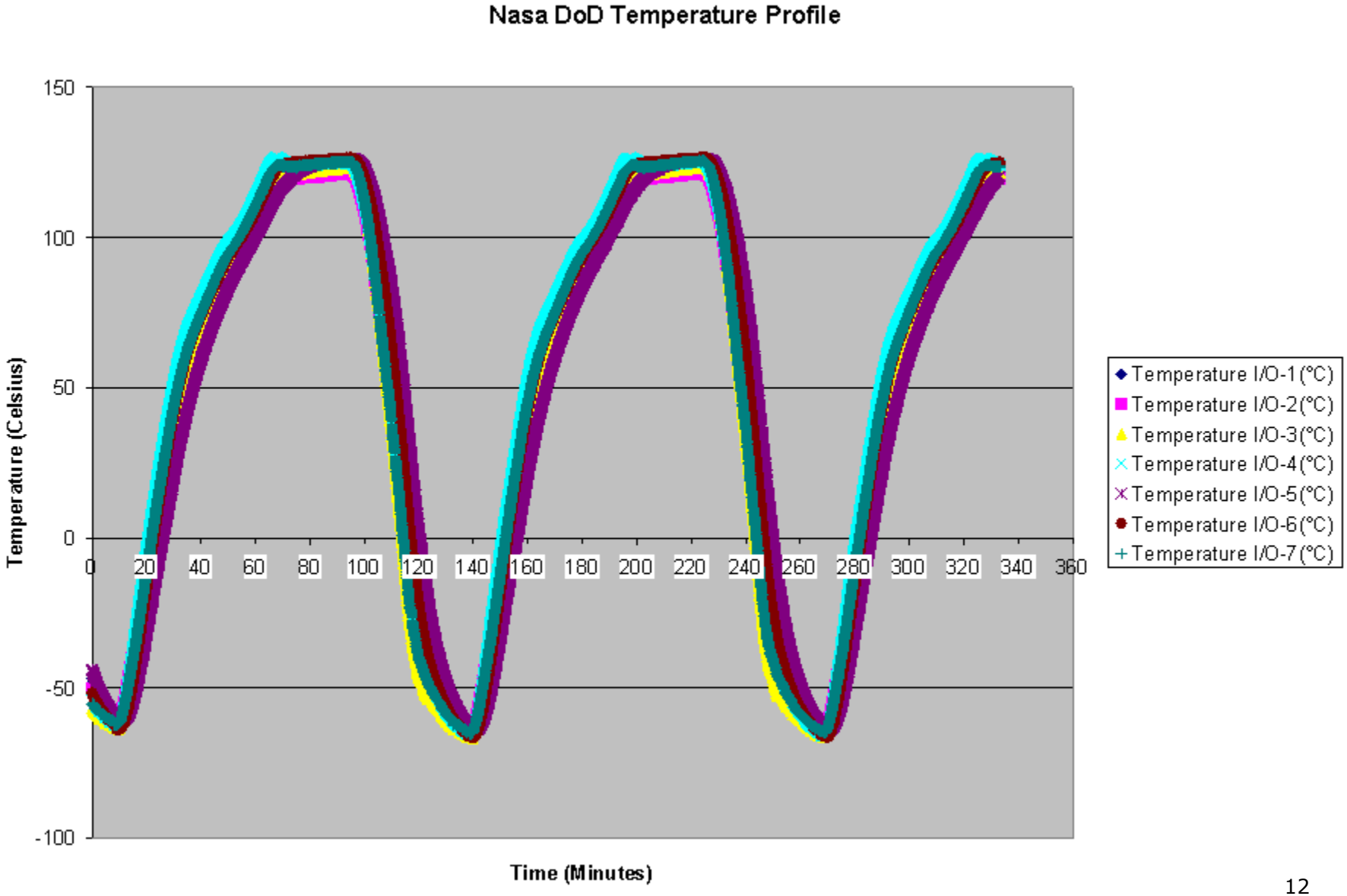
- **Five of these test assemblies were included in the -55 C to +125 C thermal cycle testing to allow for data comparison purposes.**

# Thermal Cycle Parameters

- In accordance with IPC-9701
  - Temperature Extremes: -55 C and +125 C
  - Temperature Ramp: 5-10C per minute maximum
  - Temperature Dwells: 10 minutes @ -55 C
    30 minutes @+125 C

- Continuous Monitoring with Event Detector:
  - An Event channel resistance exceeded 300 Ω for longer than 0.2 μsec within a 30-second period
  - A failure was defined when a component either:
    - 15 consecutive maximum resistance events
    - 5 consecutive detection events within 10% of current life
    - Becomes electrically open

# Thermal Cycle Profile



# Thermal Cycle Chamber - 2240 Channels

# Test Analysis & Results: after 3600 Cycles

## Manufacturing Test Vehicles

| Component Type | Total Failures | Population | Percent Failed |
|---|---|---|---|
| CLCC-20 | 232 | 311 | 74.6% |
| QFN-20 | 70 | 134 | 52.2% |
| QFP-144 | 228 | 309 | 73.8% |
| PBGA-225 | 156 | 279 | 56.0% |
| PDIP-20 | 160 | 220 | 72.7% |
| CSP-100 | 175 | 281 | 62.3% |
| TSOP-50 | 178 | 249 | 71.5% |

## Rework Test Vehicles

| Component Type | Total Failures | Population | Percent Failed |
|---|---|---|---|
| PBGA-225 | 27 | 66 | 40.9% |
| PDIP-20 | 41 | 60 | 68.3% |
| CSP-100 | 31 | 67 | 46.3% |
| TSOP-50 | 62 | 99 | 62.6% |

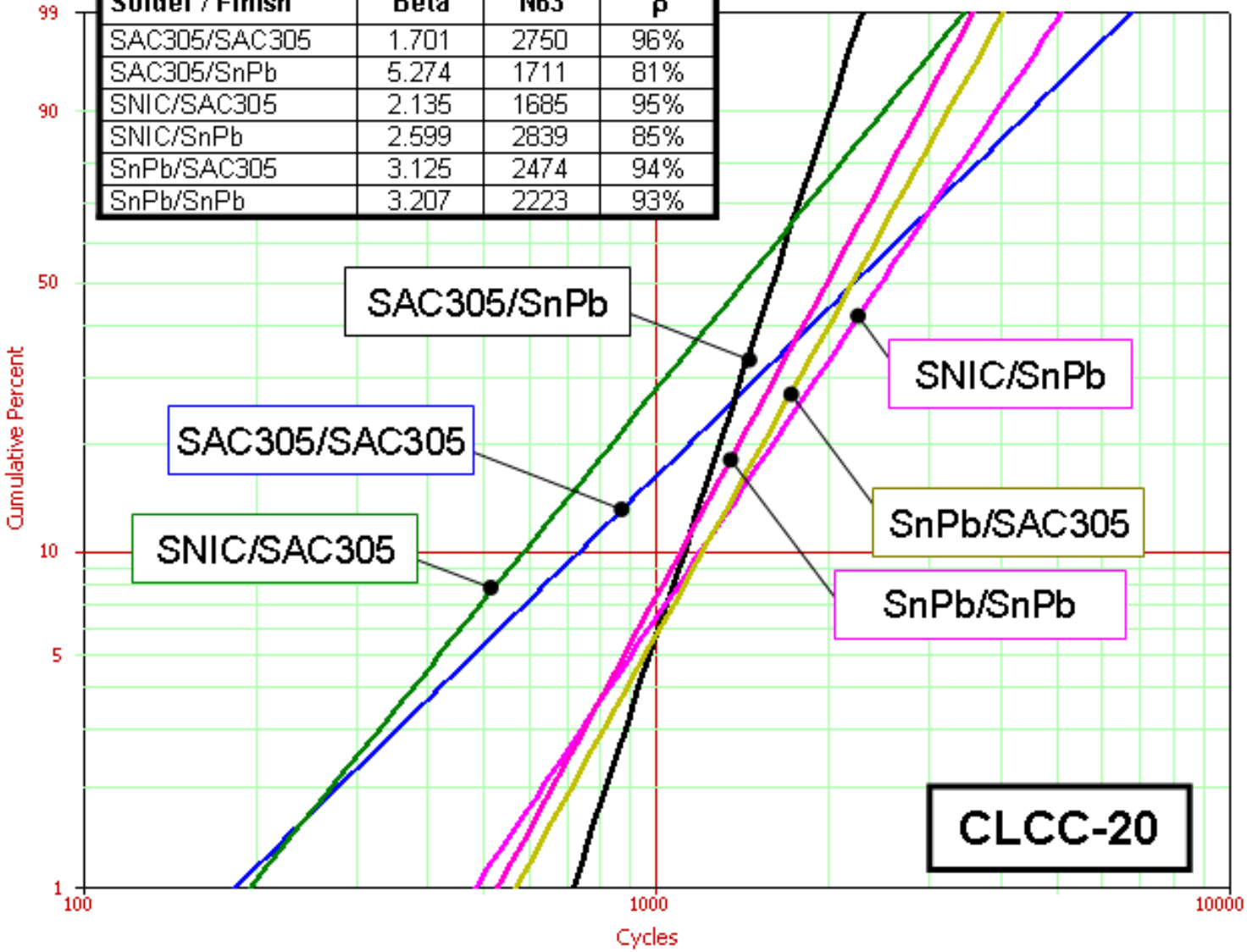
# Test Analysis & Results

NOTE – the following Weibull charts are ***PRELIMINARY ASSESSMENTS*** without physical failure analysis confirmation.

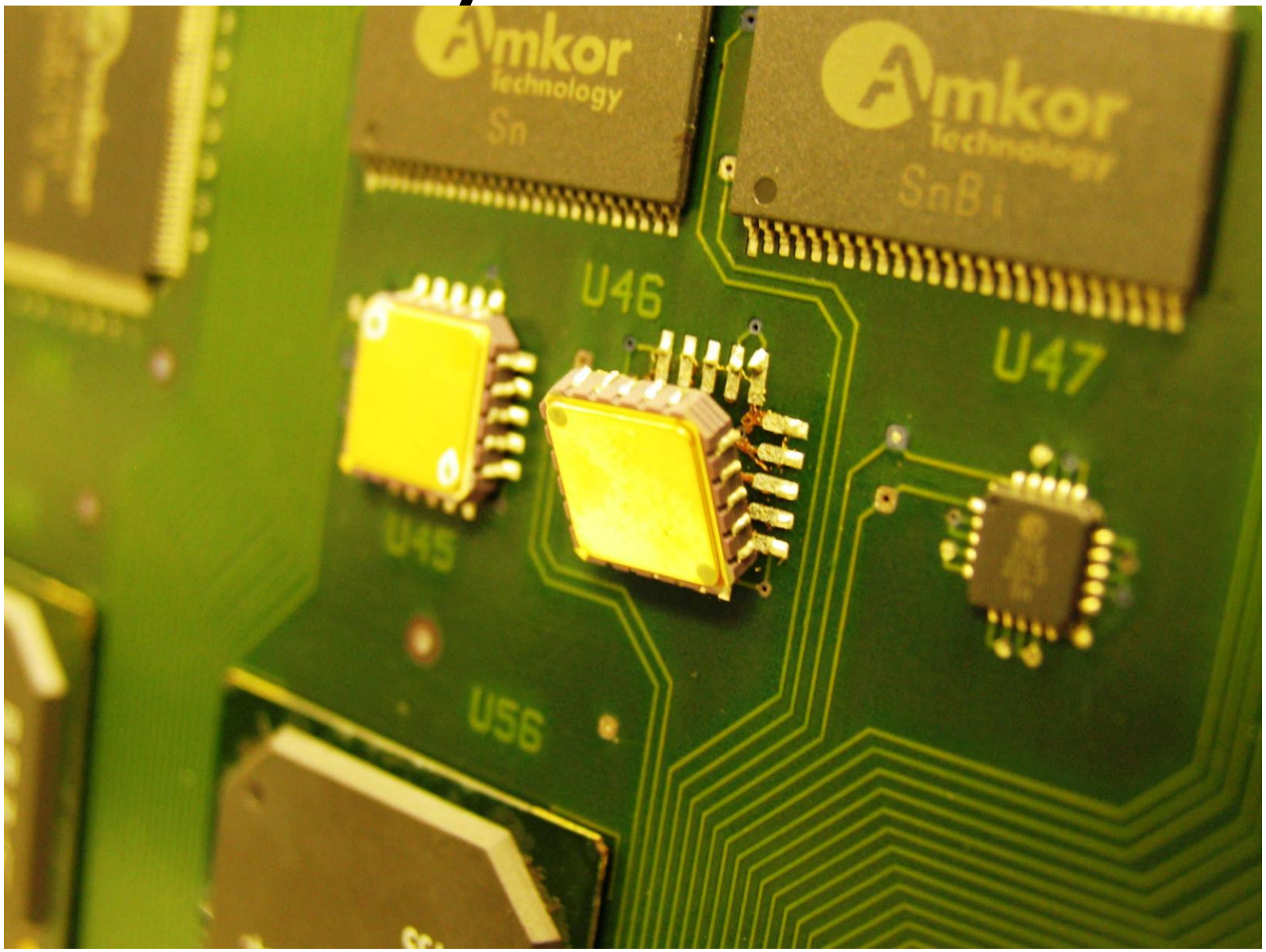
A revised set of results will be reported at a future date after thermal cycle testing is completed. Additionally, early failures will not be removed from the data set unless they have assignable cause as the Solder Joint Modeling community and other investigators would like to have access to an non-filtered test result set.

# Test Analysis & Results: CLCCs

| Solder / Finish | Beta | N63 | ρ |
|---|---|---|---|
| SAC305/SAC305 | 1.701 | 2750 | 96% |
| SAC305/SnPb | 5.274 | 1711 | 81% |
| SNIC/SAC305 | 2.135 | 1685 | 95% |
| SNIC/SnPb | 2.599 | 2839 | 85% |
| SnPb/SAC305 | 3.125 | 2474 | 94% |
| SnPb/SnPb | 3.207 | 2223 | 93% |

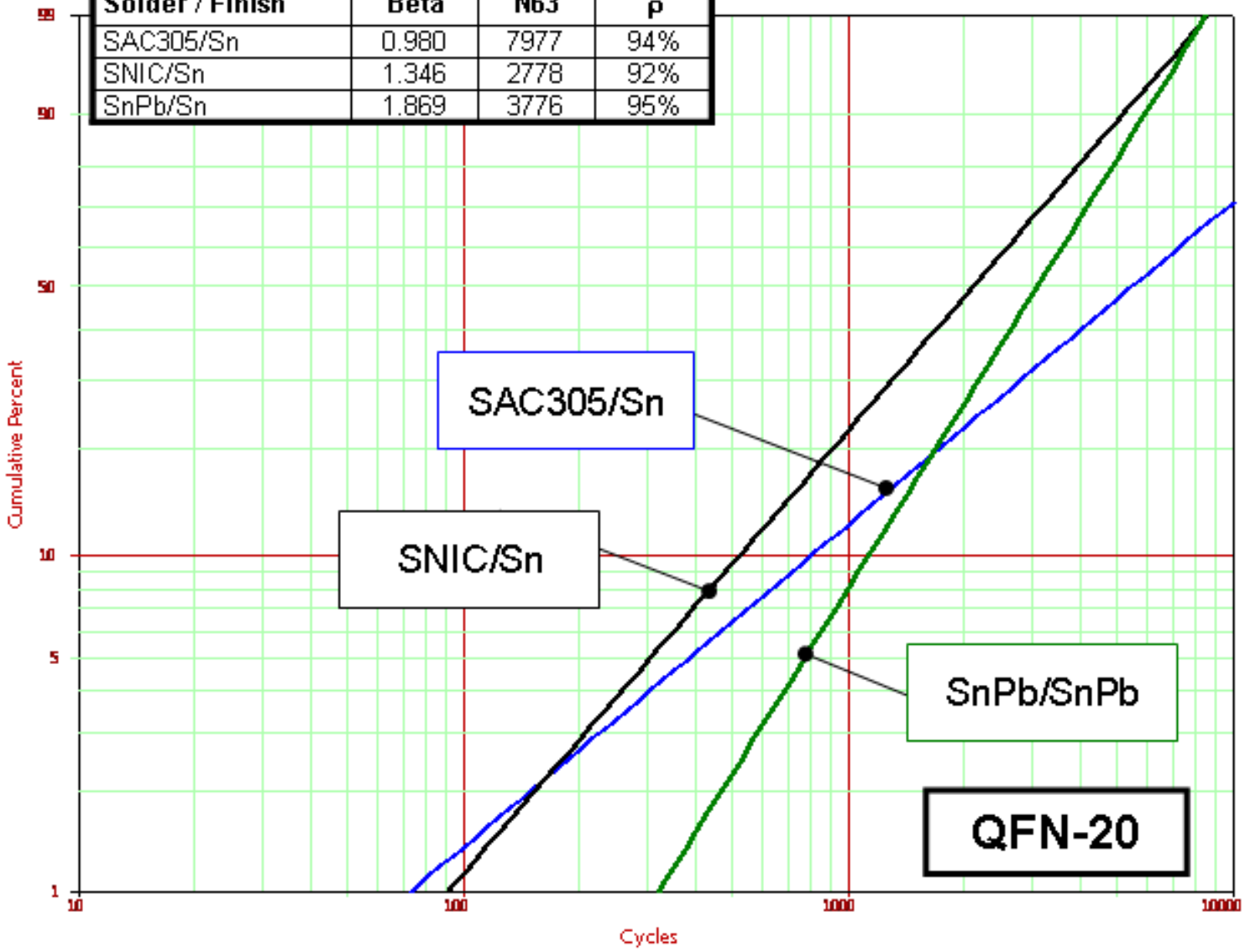


# Test Analysis & Results: CLCCs



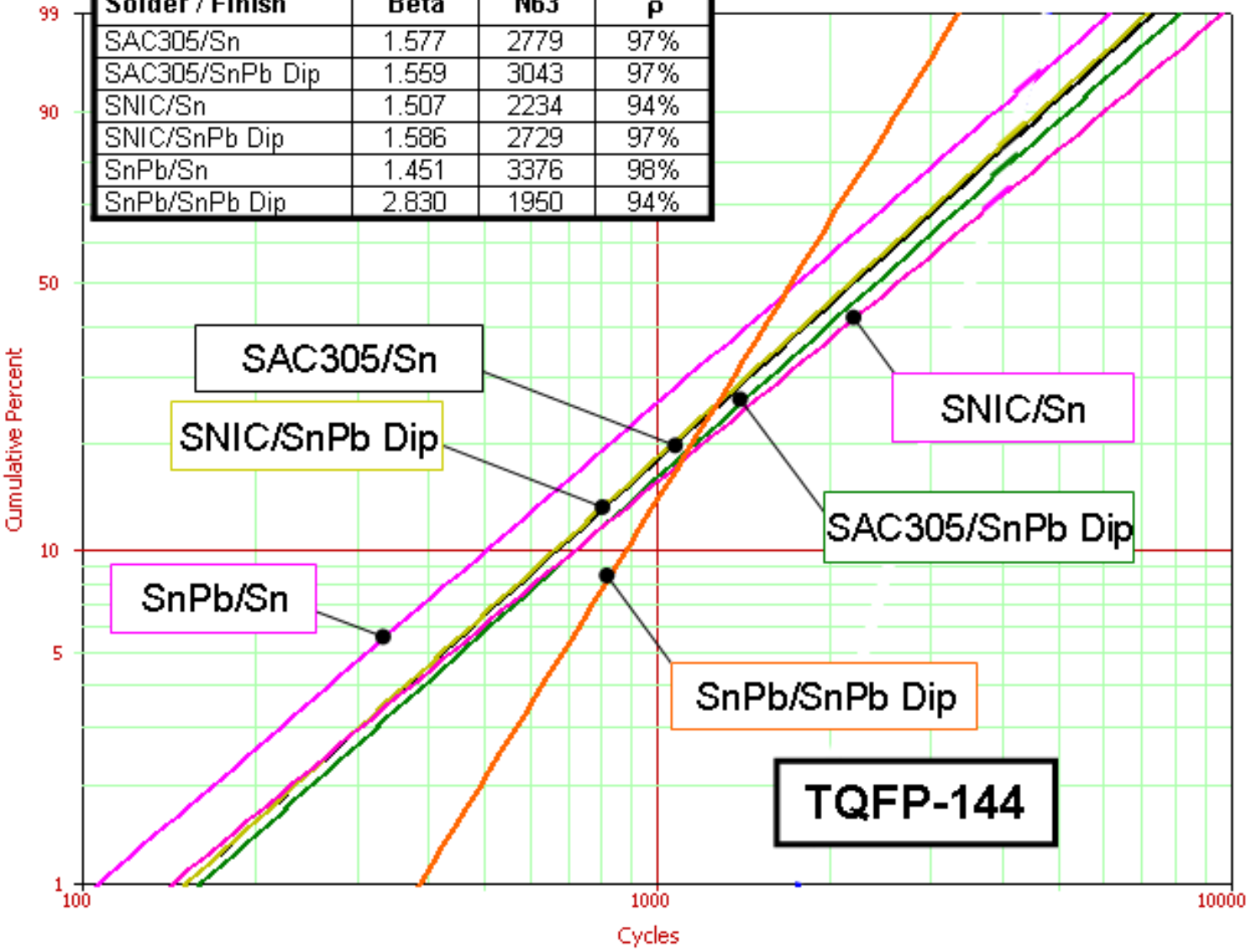
# Test Analysis & Results: QFNs

| Solder / Finish | Beta | N63 | ρ |
|---|---|---|---|
| SAC305/Sn | 0.980 | 7977 | 94% |
| SNIC/Sn | 1.346 | 2778 | 92% |
| SnPb/Sn | 1.869 | 3776 | 95% |



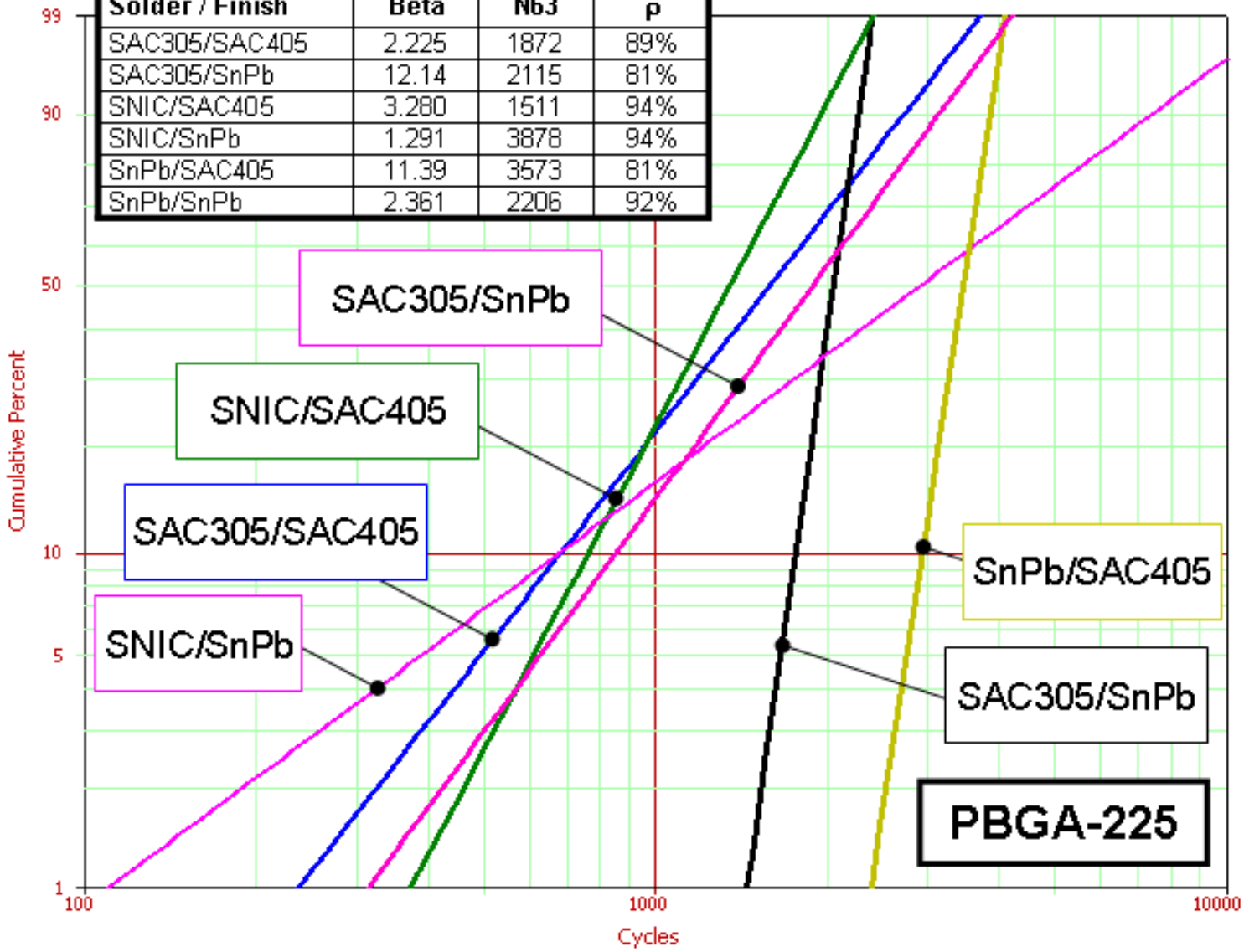
# Test Analysis & Results: QFPs

| Solder / Finish | Beta | N63 | ρ |
|---|---|---|---|
| SAC305/Sn | 1.577 | 2779 | 97% |
| SAC305/SnPb Dip | 1.559 | 3043 | 97% |
| SNIC/Sn | 1.507 | 2234 | 94% |
| SNIC/SnPb Dip | 1.586 | 2729 | 97% |
| SnPb/Sn | 1.451 | 3376 | 98% |
| SnPb/SnPb Dip | 2.830 | 1950 | 94% |



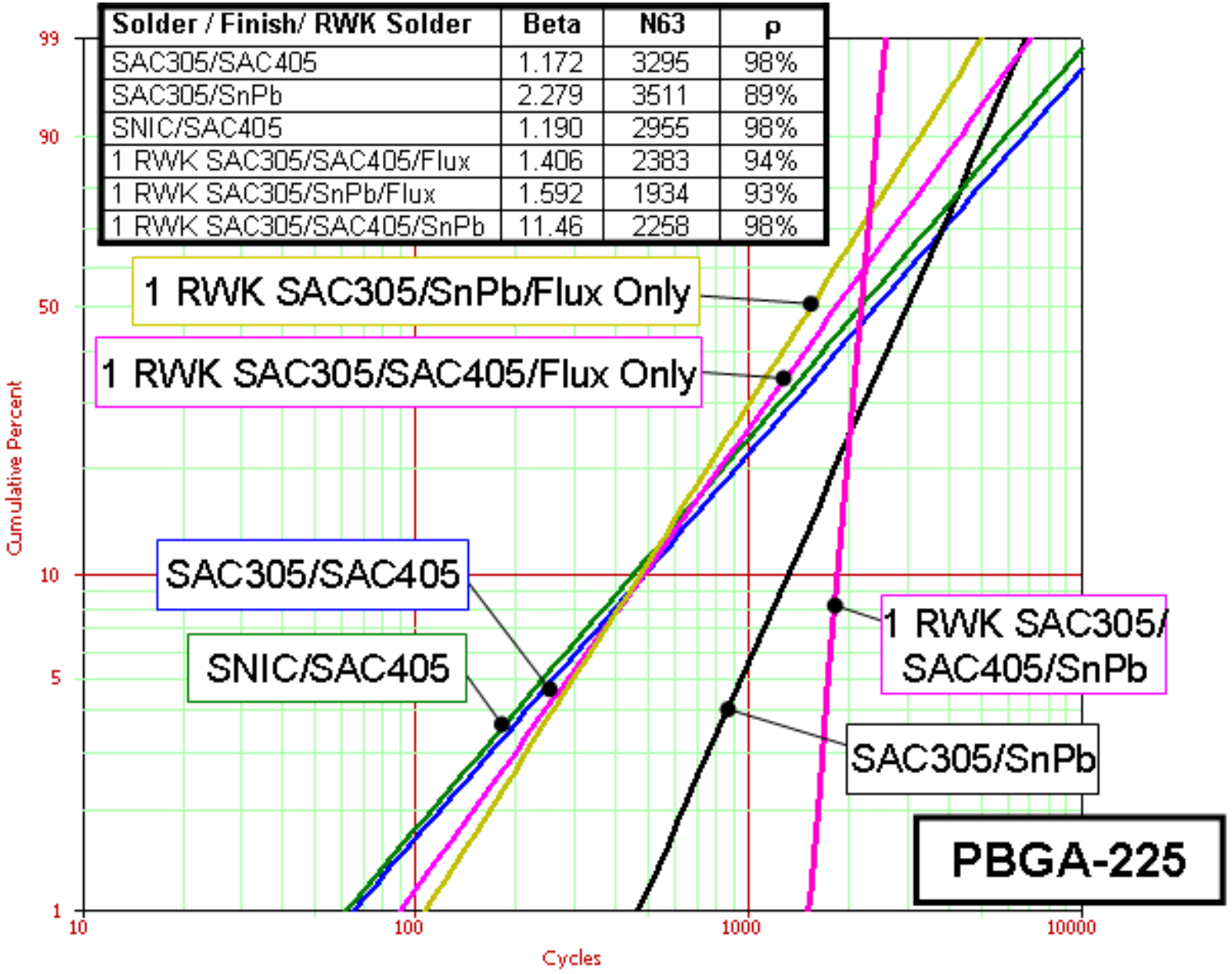
# Test Analysis & Results: BGAs

| Solder / Finish | Beta | N63 | ρ |
|---|---|---|---|
| SAC305/SAC405 | 2.225 | 1872 | 89% |
| SAC305/SnPb | 12.14 | 2115 | 81% |
| SNIC/SAC405 | 3.280 | 1511 | 94% |
| SNIC/SnPb | 1.291 | 3878 | 94% |
| SnPb/SAC405 | 11.39 | 3573 | 81% |
| SnPb/SnPb | 2.361 | 2206 | 92% |



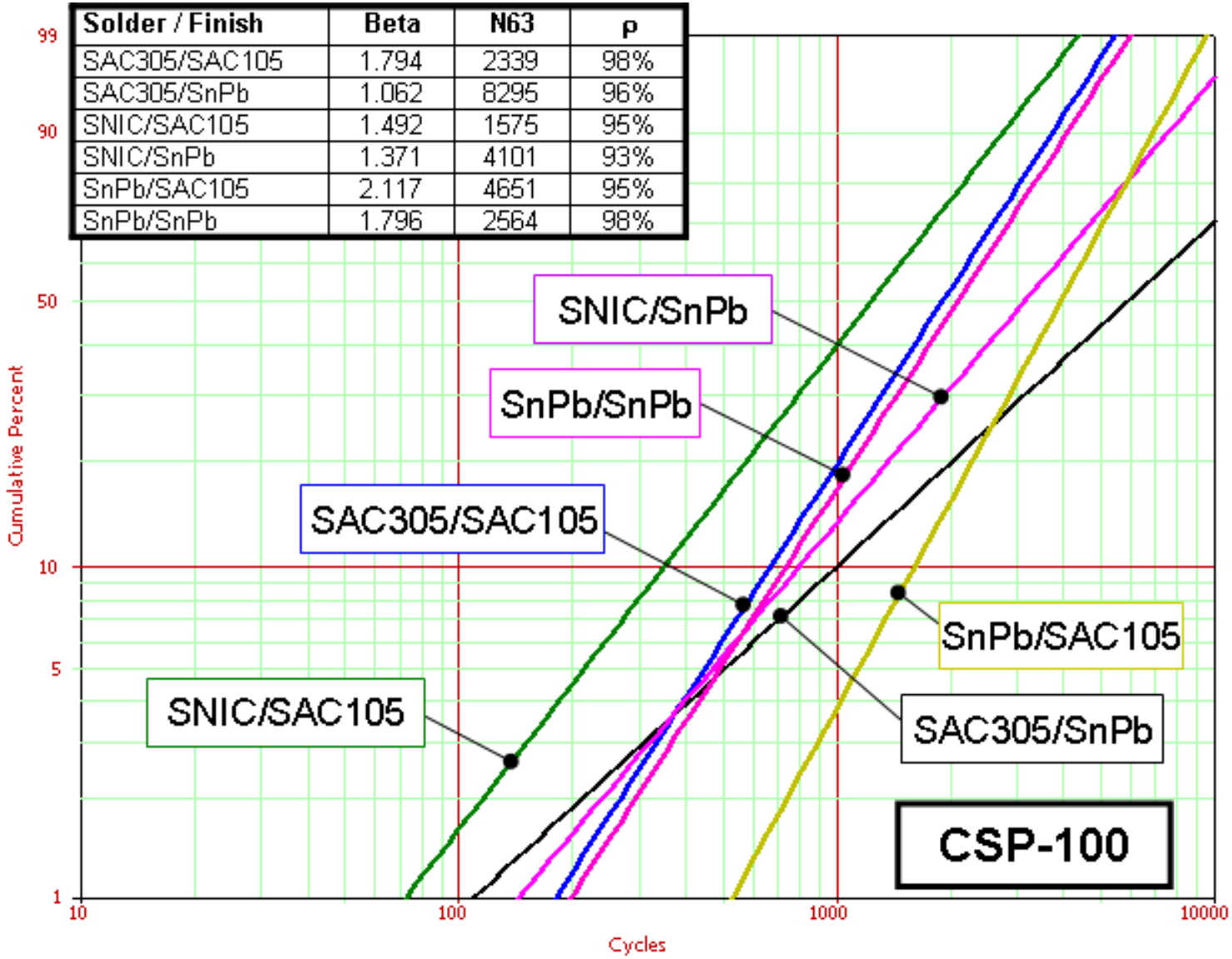
# Test Analysis & Results: BGAs Reworked

| Solder / Finish/ RWK Solder | Beta | N63 | ρ |
|---|---|---|---|
| SAC305/SAC405 | 1.172 | 3295 | 98% |
| SAC305/SnPb | 2.279 | 3511 | 89% |
| SNIC/SAC405 | 1.190 | 2955 | 98% |
| 1 RWK SAC305/SAC405/Flux | 1.406 | 2383 | 94% |
| 1 RWK SAC305/SnPb/Flux | 1.592 | 1934 | 93% |
| 1 RWK SAC305/SAC405/SnPb | 11.46 | 2258 | 98% |



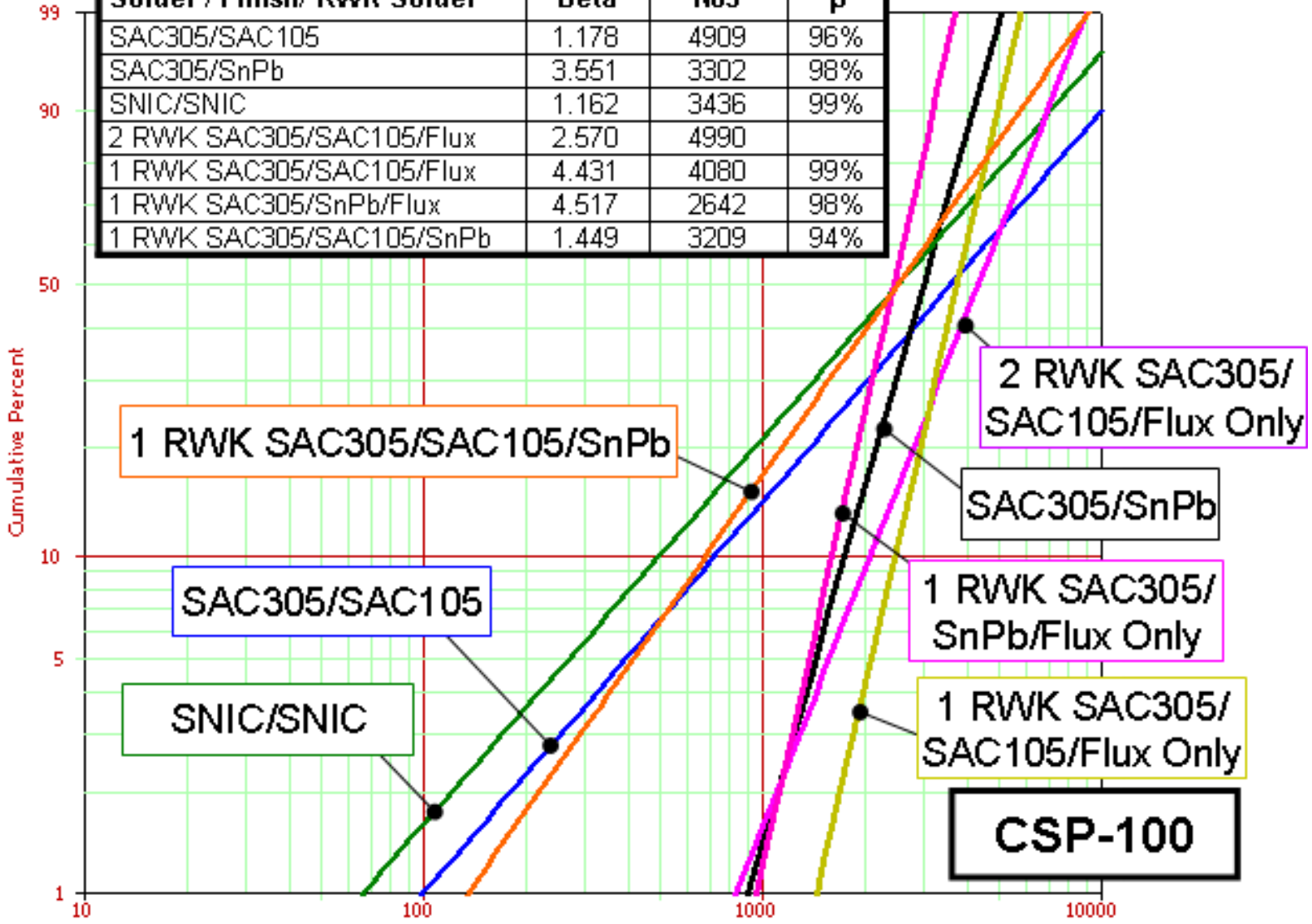
# Test Analysis & Results: CSPs

| Solder / Finish | Beta | N63 | ρ |
|---|---|---|---|
| SAC305/SAC105 | 1.794 | 2339 | 98% |
| SAC305/SnPb | 1.062 | 8295 | 96% |
| SNIC/SAC105 | 1.492 | 1575 | 95% |
| SNIC/SnPb | 1.371 | 4101 | 93% |
| SnPb/SAC105 | 2.117 | 4651 | 95% |
| SnPb/SnPb | 1.796 | 2564 | 98% |



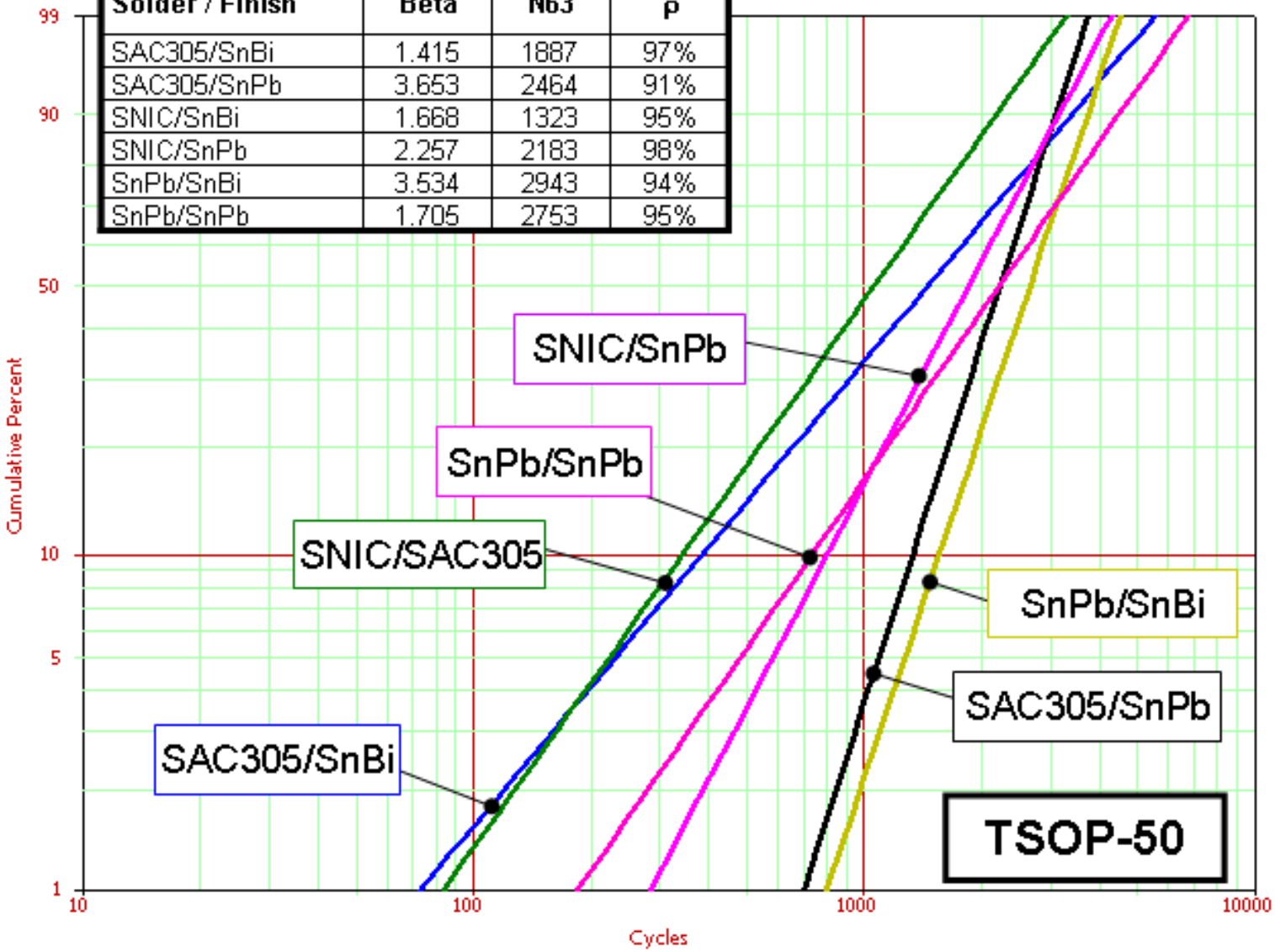
# Test Analysis & Results: CSPs Reworked

| Solder / Finish/ RWK Solder | Beta | N63 | ρ |
|---|---|---|---|
| SAC305/SAC105 | 1.178 | 4909 | 96% |
| SAC305/SnPb | 3.551 | 3302 | 98% |
| SNIC/SNIC | 1.162 | 3436 | 99% |
| 2 RWK SAC305/SAC105/Flux | 2.570 | 4990 | |
| 1 RWK SAC305/SAC105/Flux | 4.431 | 4080 | 99% |
| 1 RWK SAC305/SnPb/Flux | 4.517 | 2642 | 98% |
| 1 RWK SAC305/SAC105/SnPb | 1.449 | 3209 | 94% |

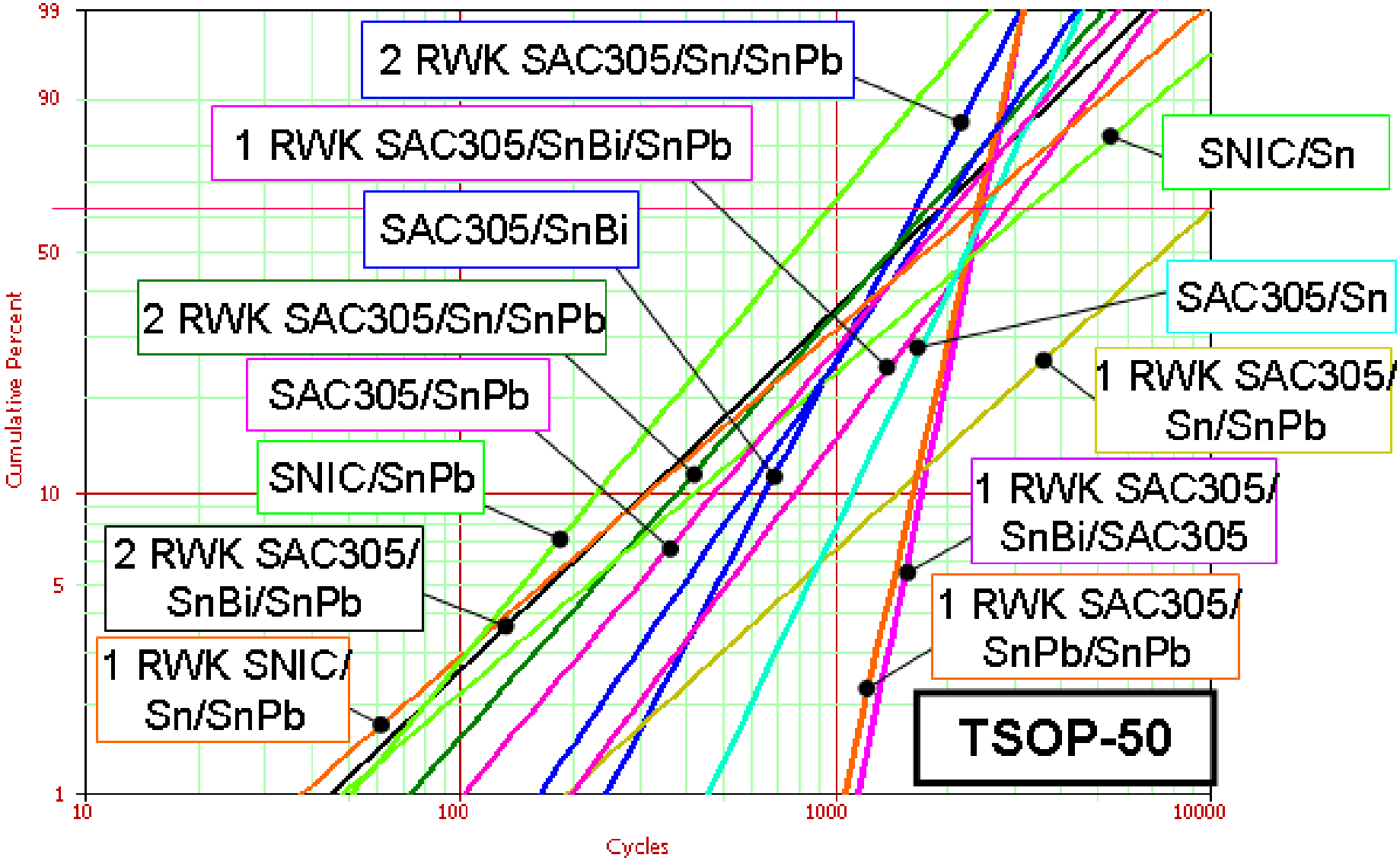


# Test Analysis & Results: TSOPs

| Solder / Finish | Beta | N63 | ρ |
|---|---|---|---|
| SAC305/SnBi | 1.415 | 1887 | 97% |
| SAC305/SnPb | 3.653 | 2464 | 91% |
| SNIC/SnBi | 1.668 | 1323 | 95% |
| SNIC/SnPb | 2.257 | 2183 | 98% |
| SnPb/SnBi | 3.534 | 2943 | 94% |
| SnPb/SnPb | 1.705 | 2753 | 95% |

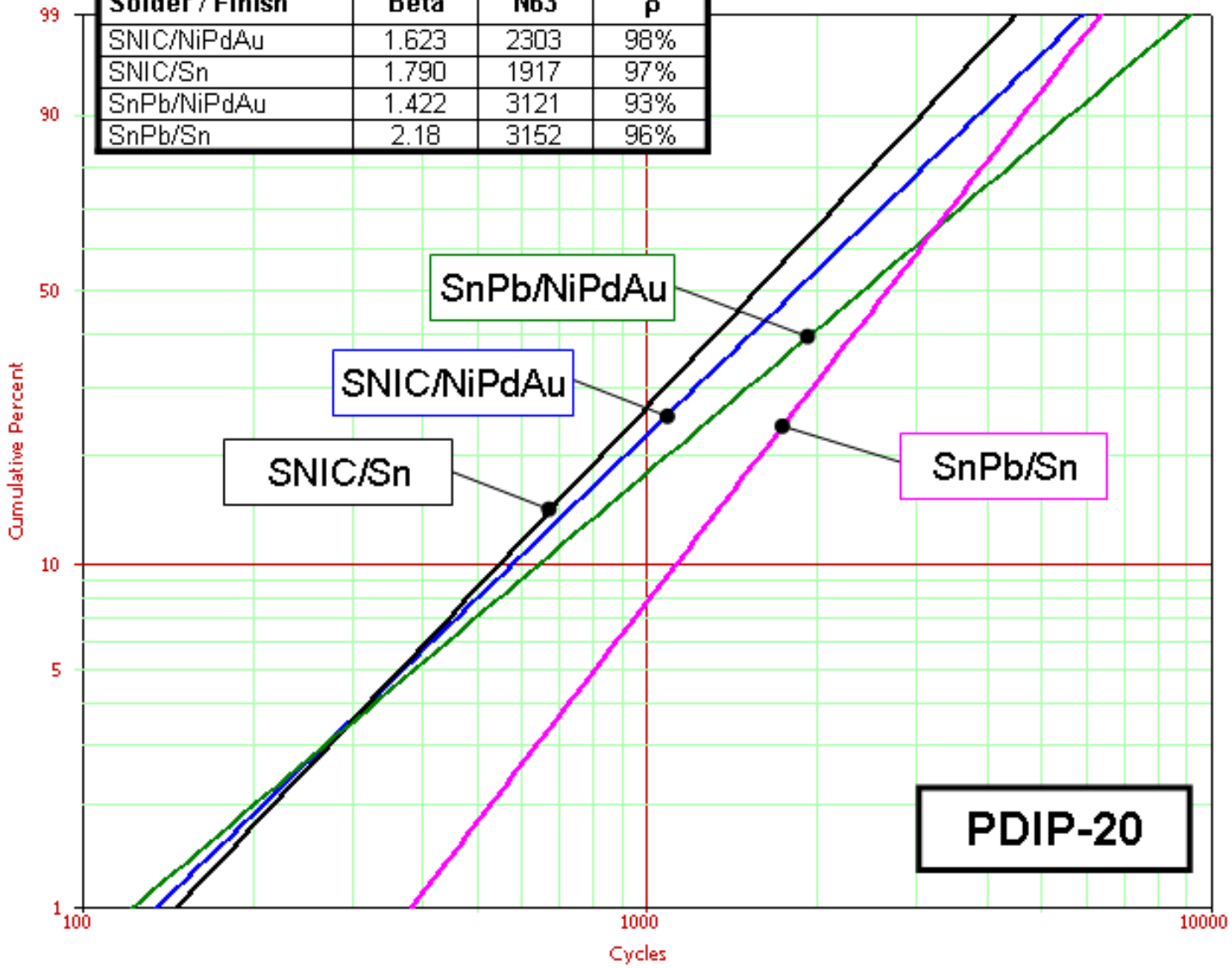


# Test Analysis & Results: TSOPs Reworked



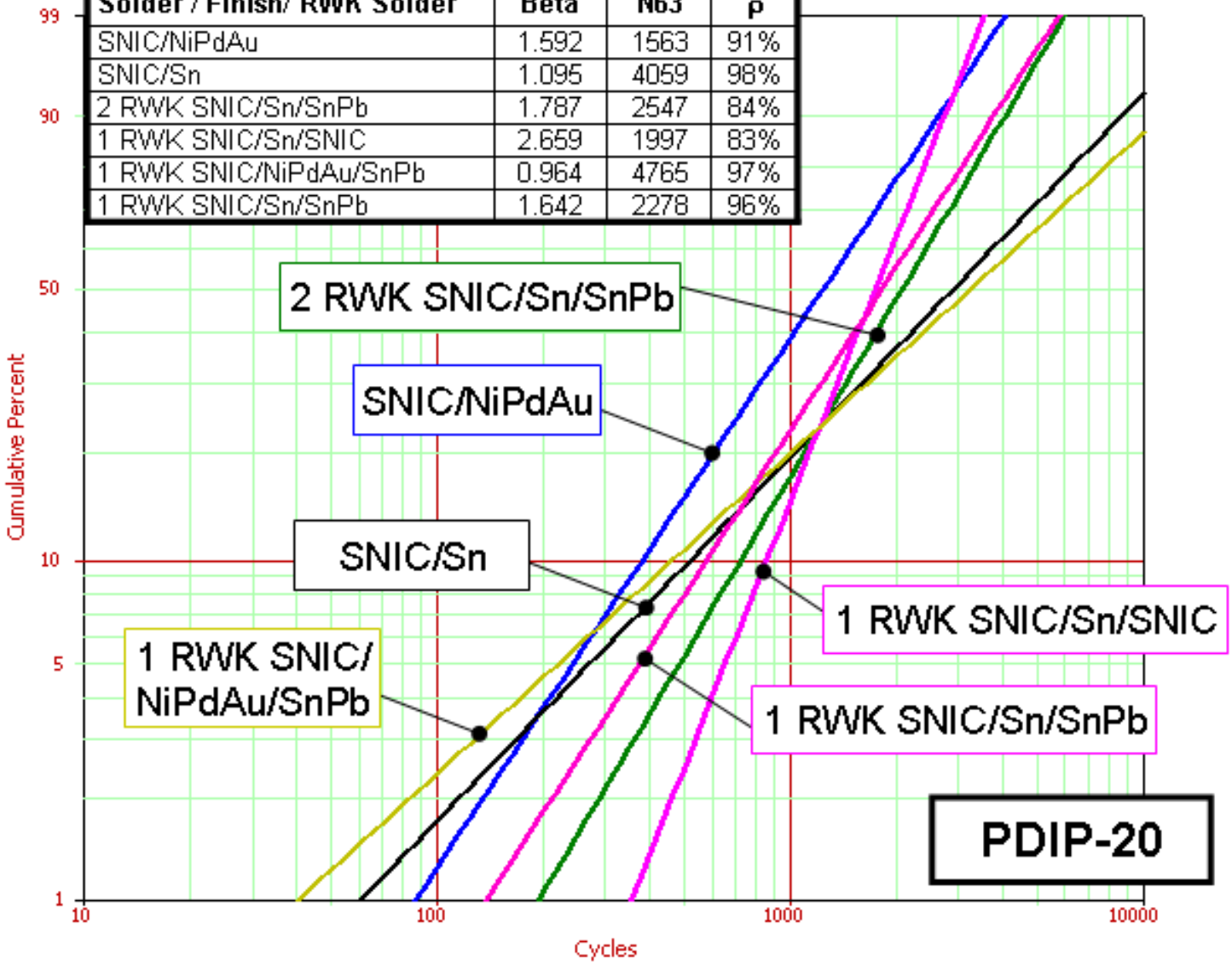
# Test Analysis & Results: PDIPs

| Solder / Finish | Beta | N63 | ρ |
|---|---|---|---|
| SNIC/NiPdAu | 1.623 | 2303 | 98% |
| SNIC/Sn | 1.790 | 1917 | 97% |
| SnPb/NiPdAu | 1.422 | 3121 | 93% |
| SnPb/Sn | 2.18 | 3152 | 96% |

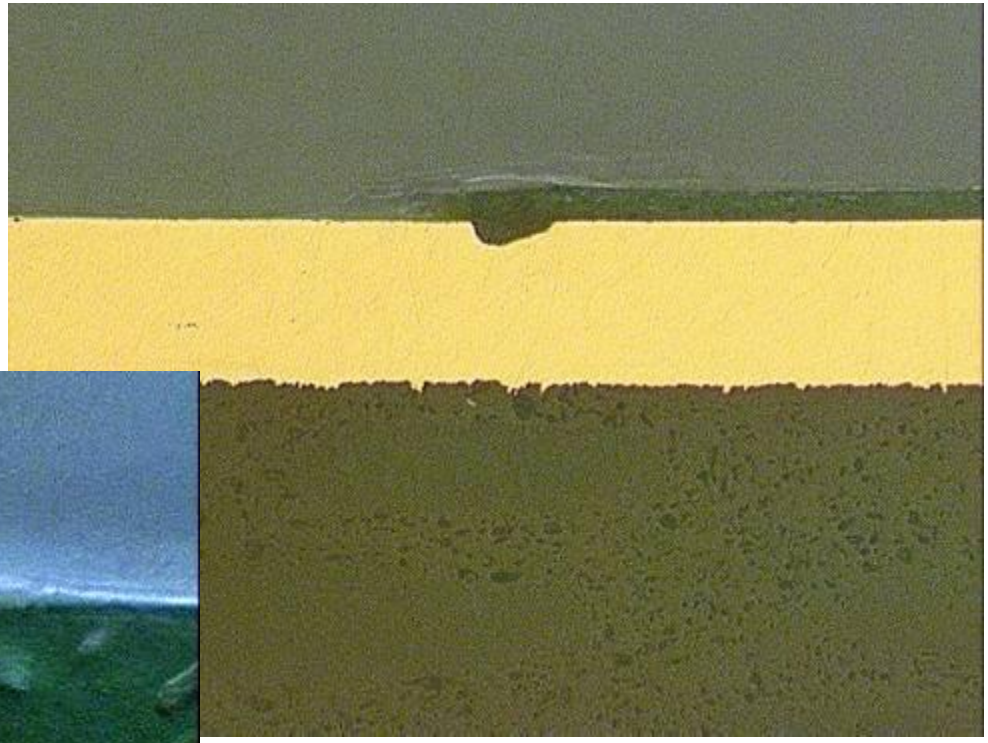


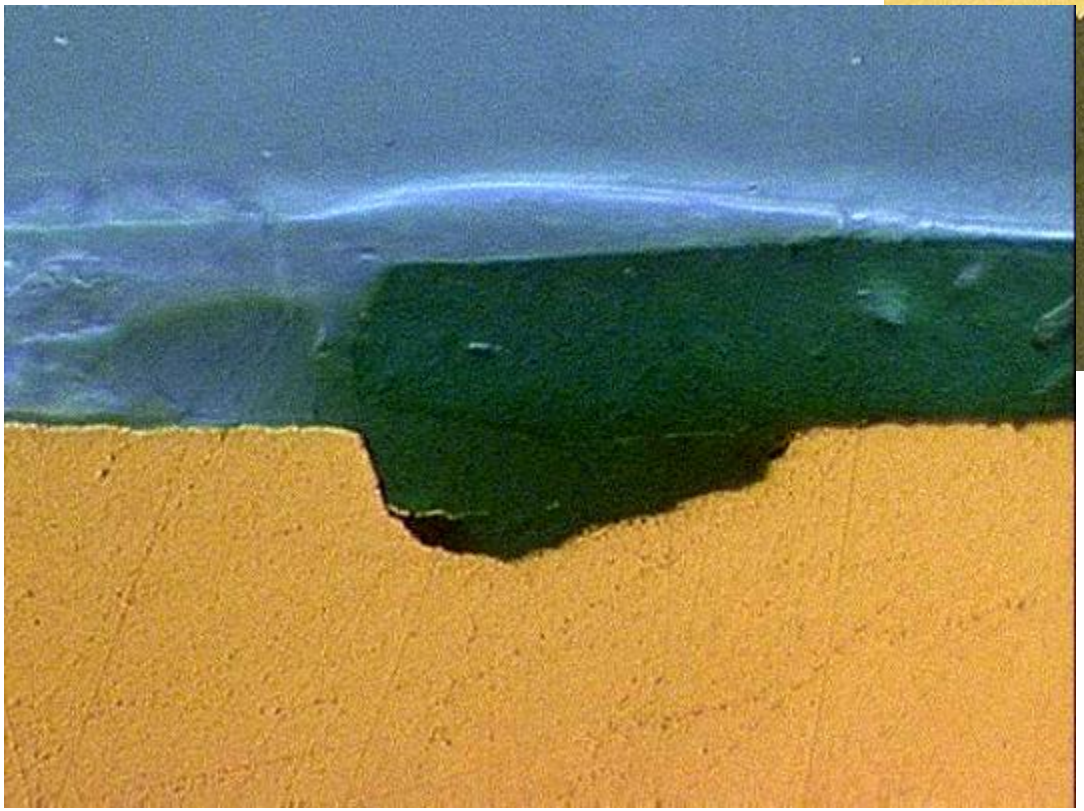
# Test Analysis & Results: PDIPs Reworked

| Solder / Finish/ RWK Solder | Beta | N63 | ρ |
|---|---|---|---|
| SNIC/NiPdAu | 1.592 | 1563 | 91% |
| SNIC/Sn | 1.095 | 4059 | 98% |
| 2 RWK SNIC/Sn/SnPb | 1.787 | 2547 | 84% |
| 1 RWK SNIC/Sn/SNIC | 2.659 | 1997 | 83% |
| 1 RWK SNIC/NiPdAu/SnPb | 0.964 | 4765 | 97% |
| 1 RWK SNIC/Sn/SnPb | 1.642 | 2278 | 96% |



# Test Analysis & Results: PDIP FA





# PRELIMINARY!! General Observations

**CLCC: Generally had Weibull Slopes ~2-3, with N63 ~ 2500; no strong trends regarding SnPb vs. Pb-free**

**QFN: Weibull slopes ~1-2; SnPb had the highest slope of parts tested (more uniform reliability)**

**QFP: Weibull slopes all ~1.5 except for one combination (SnPb/SnPb Dip); N63 for all components ~2000-3000 cycles**

**BGA: Significant range in slopes (~1.2 – 12) and N63 (~1500 – 3900) without clear trends as to cause. Parts on reworked boards had larger N63s; reworked parts had slightly higher slopes than non-reworked**

**CSP: Weibull slopes ~1-2, N63s ~2000-4000 cycles; SnPb parts had somewhat better reliability; reworked parts generally more reliable**

**TSOP: Weibull slopes ranged from ~1.4 to 3.7, N63s ~2000-3000 cycles; significant differences among parts – analysis needed to understand**

**PDIP: Weibull slopes 1.5-2, SnPb/Sn had best reliability; Low slope may have been due to component defect**

# Future Work & Preliminary FA Results :

- Completion of thermal cycling of test vehicles – **4068 Cycles Total**
- Assessment for tin pest phenomenon – **DONE, No Observations**
- Assessment for tin whisker phenomenon – **DONE, No Observations**
- Assessment for pad cratering phenomenon
- Assessment for printed wiring board fabrication defects and anomalies
- Assessment for BGA/CSP process void and shrinkage void phenomenon
- Assessment PDIP-20 for copper dissolution degradation
- Metallographic cross-sectional analysis of solder joint failures
- Scanning Electron Microscopy (SEM) analysis including solder joint microstructure phase identification and elemental mapping
- Analysis of mixed metallurgy impact on solder joint integrity
- Verification of statistical analysis calculations

# Questions?